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SUB-WOOFER WITH TWO  
PASSIVE RADIATORS

EUGUENE J CZERWINSKI

1        This application is a continuation-in-part of an  
2 application, filed March 14, 2000 under Serial No.  
3 09/523,870, now U. S. Patent No. 6,343,134, which is a  
4 continuation-in-part of an application, filed Jan. 28, 1998  
5 under Serial. No. 09/014,700, now U. S. Patent No.  
6 6,038,326, and a continuation-in-part of an application,  
7 filed October 9, 2001 under Serial No. 09/973,472.

8        BACKGROUND OF THE INVENTION

9        The present invention relates generally to the field of  
10 high fidelity audio reproduction and more particularly to  
11 subwoofer loudspeaker systems that produce high quality, low  
12 distortion and low-frequency sound.

13

14        U. S. Patent No. 6,343,134 and U. S. Patent No.  
15 6,038,326 teach a loudspeaker that includes a compression

1 chamber, a first electro-acoustic transducer and a horn. The  
2 first electro-acoustic transducer is disposed inside the  
3 compression chamber. The horn is mechanically and  
4 acoustically coupled to the first electro-acoustic  
5 transducer. The loudspeaker also includes a second electro-  
6 acoustic transducer. The second electro-acoustic transducer  
7 is disposed outside the compression chamber. The second  
8 electro-acoustic transducer is mechanically and acoustically  
9 coupled to the horn.

10 U. S. Patent No. 4,138,594 teaches a small dimension  
11 low frequency loudspeaker that includes a folded exponential  
12 horn which provides a unitary curved sound path from an  
13 electro-acoustic transducer at the throat of the horn to a  
14 volume into which sound is radiated at the mouth of the  
15 horn. The length of the horn is such that, at an  
16 exponential rate of expansion between the throat and the  
17 mouth, the mouth, when it is bounded by at least one planar  
18 surface, such as a floor, a ceiling, and/or walls of a room,

1 has adequate area to enable reproduction of low audible  
2 frequencies. The low frequency loudspeaker has an effective  
3 low end cut-off frequency of 55 Hz. U. S. Patent No.  
4 4,210,223 teaches a low frequency loudspeaker apparatus  
5 includes a folded exponential horn that is divided to  
6 provide a bifurcated curved sound path from at least one  
7 electro-acoustic transducer that is positioned at the throat  
8 of the horn to a volume into that sound waves are radiated  
9 that is located at the bifurcated mouth of the horn. The  
10 mean length of the folded exponential horn is such that, at  
11 an exponential rate of expansion between the throat and the  
12 bifurcated mouth, the area of the mouth is adequate for  
13 reproduction of low frequencies in the audible range. The  
14 low frequency loudspeaker apparatus has an effective low end  
15 cut-off frequency of 38 Hz and affords 99 dB SPL output at  
16 three meters with one watt input which corresponds to about  
17 20% efficiency measured in free space. Presence of a single  
18 boundary surface, such as a stage floor adjacent the mouth

1 of the folded exponential horn, improves amplitude response  
 2 by 3 to 6 dB. A small dimension low frequency folded  
 3 exponential horn loudspeaker has a unitary sound path for  
 4 direction of acoustical waves from an electro-acoustic  
 5 transducer to a volume into which the acoustical waves are  
 6 radiated.

7 High fidelity sound reproduction requires reproduction  
 8 of low audible frequencies. W. B. Snow, "Audible Frequency  
 9 Ranges of Music, Speech, and Noise," Jour. Acous. Soc. Am.,  
 10 Vol. 3, July, 1931, p. 155, for example, indicates that high  
 11 fidelity sound reproduction of orchestral music requires  
 12 that the frequency band should extend to as low as 40 Hz.  
 13 It is well established that loudspeakers, in order to  
 14 reproduce a given frequency range, must have dimensions  
 15 based on the wavelength which corresponds to the lowest  
 16 frequency in the range. In the case of one type of  
 17 loudspeaker, the exponential horn loudspeaker, for example,  
 18 the area of the exponential horn mouth is determined on the

1 basis of the wavelength of the lowest frequency to be  
2 reproduced. At an early date, to obtain high fidelity sound  
3 reproduction with exponential horn loudspeakers, and, in  
4 particular, the inclusion of low audible frequencies, large  
5 exponential horn loudspeakers were constructed. For  
6 example, theater loudspeakers as large or larger than eight  
7 feet in length and four feet by four feet in transverse  
8 dimensions were built in order to obtain reproduction of low  
9 audible frequencies. Later, the outside dimensions of the  
10 exponential horns were reduced by folding, but even then the  
11 dimensions of the mouths were large for reproduction of low  
12 audible frequencies. More recently, folded exponential horn  
13 loudspeakers with reduced mouth dimensions have been used in  
14 proximity to boundary surfaces, such as a floor, a ceiling,  
15 and/or walls of a room, to increase the effective mouth area  
16 so that low audible frequencies are reproduced while at the  
17 same time the dimensions of the low frequency loudspeakers  
18 are minimized. See, for example, Sandeman, U. S. Patent No.

1 1,984,550, U. S. Patent No. 2,310,243 and U. S. Patent No.  
2 2,373,692, and Klipsch, "La Scala, " Audio Engineering  
3 Society Preprint No. 372, Apr. 1965. The low frequency  
4 folded exponential horn loudspeakers, such as those  
5 which are disclosed in the above-cited references, have  
6 small dimensions and, when their mouths are located  
7 proximate planar surfaces, enable reproduction of  
8 low audible frequencies. However, each of these low  
9 frequency folded exponential horn loudspeakers is  
10 structurally complex due to the structure of the folded  
11 exponential horn that defines the sound path from the  
12 electro-acoustic transducer to the volume into which sound  
13 is radiated. Perhaps the simplest construction appears in  
14 the above-cited Audio Engineering Society publication.  
15 In that construction, the folded exponential horn is  
16 bifurcated to define a double sound path. Due to the complex  
17 structure, the production of high fidelity, small dimension,  
18 low frequency folded exponential horn loudspeakers has

1 required considerable craftsmanship. High quality control  
2 in manufacture has been necessary to assure that the  
3 construction meet specifications. Consequently, the cost of  
4 low frequency folded exponential horn loudspeakers has been  
5 high.

6 U. S. Patent No. 5,212,732 teaches a loudspeaker system  
7 of the dipole type, particularly for use in surround sound,  
8 reverberation and similar applications. A speaker system  
9 includes a pair of woofers having dual voice coil drivers  
10 mounted on oppositely facing baffles (e.g., front and rear  
11 facing). Preferably, each baffle also includes a high  
12 frequency speaker mounted thereon. On a first baffle (e.g.,  
13 front), both voice coils of the dual voice coil driver and  
14 the voice coil of the high frequency speaker are driven in-  
15 phase, and on the other baffle (e.g., rear), the second  
16 voice coil of the dual voice coil driver and the voice coil  
17 of the high frequency speaker are driven out-of-phase from  
18 those from the first baffle but in-phase with one another.

1 The coils of the speakers are driven from suitable filter  
2 circuits.

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10 coils of the dual voice coil driver and the voice coil of  
11 the high frequency speaker are driven in-phase, and on the  
12 other baffle (e.g., rear), the second voice coil of the dual  
13 voice coil driver and the voice coil of the high frequency  
14 speaker are driven out-of-phase from those from the first  
15 baffle but in-phase with one another. The coils of the  
16 speakers are driven from suitable filter circuits. Various  
17 forms of loudspeaker systems have been developed, and the  
18 types of speakers as well as the technologies involved



1 pertaining to woofers, tweeters, mid-range and other forms  
 2 of speaker systems are well known. Stereo sound systems  
 3 using front speakers with or without some form of woofer or  
 4 subwoofer, along with rear and/or side speakers, have become  
 5 prevalent particularly for sound systems used to reproduce  
 6 sound in "home theater" video systems for playing back video  
 7 motion pictures and similar program material. The typical  
 8 installation comprises a pair of front speakers positioned  
 9 to either side of the TV screen, preferably with a center  
 10 speaker and/or a subwoofer, and along with a pair of right  
 11 and left side speaker and/or a pair of left and right rear  
 12 speakers.

13       An Audio Engineering Society (AES) paper entitled "New  
 14 Factors in Sound for Cinema and Television" by Tomlinson  
 15 Holman, presented at the 89th Convention of the Audio  
 16 Engineering Society, Los Angeles, Calif., Sep. 21-25, 1990,  
 17 and reprinted in the Journal of the AES, Volume 39, No. 7/8,  
 18 (preprint #2945) notes that the best directivity pattern for

1 the "surround" loudspeakers is not the conventional forward  
2 radiating direct radiator, but rather dipolar radiation  
3 with the principal lobes of the dipole pointed, not at the  
4 listening area, but at the room surfaces with the null in  
5 the radiation pattern pointed at listeners, and that the  
6 best surround loudspeaker is physically invisible.

7 U. S. Patent No. 4,733,749 teaches a loudspeaker system  
8 for low frequencies has a manifold chamber into which  
9 oppositely mounted and aligned woofer units radiate sound.  
10 The chamber radiates the sound perpendicularly to the woofer  
11 axes, either directly into space or into a horn. An  
12 additional back woofer may radiate directly in the  
13 perpendicular direction. An arrangement of speakers for a  
14 low-frequency sound reproduction is system particularly  
15 adapted for high power output and has manifold for coupling  
16 multiple low frequency loudspeakers, in a single sound-  
17 radiating enclosure. Multiple loudspeakers are often used  
18 in sound applications requiring high acoustic power output

1 (sound volume), such as in theaters or arenas, or for studio  
2 and stage monitoring, discotheques and the like. In many  
3 sound systems, several components, such as driver/horn  
4 assemblies or cone/enclosure loudspeakers, are used for  
5 sound reproduction across the entire range of audible sound,  
6 with different devices covering the bass (low-frequency),  
7 midrange and high-frequency portions of the sound spectrum.

8 Low-frequency speakers are customarily referred to as  
9 "woofers". A particular sound application may require an  
10 especially high power output across the whole audio  
11 spectrum. With respect to the low-frequency range, this has  
12 been accomplished in the past, in general, by increasing the  
13 number of loudspeakers, because of the need to set large  
14 volumes of air in motion to create high acoustic power. In  
15 order to move large air volumes, the excursion of a moving  
16 diaphragm having a given cone area could be increased, but  
17 since acoustic distortion increases with increasing  
18 excursion once the linear limitation of the loudspeaker

1 suspension is reached, the solution of using multiple  
2 loudspeakers is generally preferred. Multiple loudspeakers  
3 are conventionally mounted on a front baffle board of a  
4 speaker housing or enclosure. The housing may be closed, or  
5 may be provided with one or more phase-inverting ports or  
6 ducts (as in a bass-reflex type enclosure). Acoustic  
7 coupling and addition occurs in such structures at  
8 frequencies where the wavelengths are sufficiently greater  
9 than the distances between the individual speakers or phase-  
10 inverting ports.

11 U. S. Patent No. 4,391,346 and U. S. Patent No.  
12 4,437,540 teach individual speaker units which are set in  
13 the walls of a cavity behind a front baffle board. The  
14 speaker units are arranged so that the sound-radiating axis  
15 of each speaker unit angularly converges on and is  
16 concentrated on a point of the central axis of the cavity,  
17 just behind the front baffle, toward which the speakers are  
18 generally aimed. While such an arrangement may improve mid-

1 range sound reproduction, low-end frequency reproduction is  
2 adversely affected, as the cavity behaves like a short  
3 acoustic horn having a rapid flare rate, such a horn being  
4 incapable of sustaining very low-frequency sounds. A  
5 maximum output speaker system for high-volume sound. A more  
6 specific object is to provide an efficient arrangement for  
7 summing the outputs of a number of individual low-frequency  
8 speakers for radiation from a single sound-radiating  
9 aperture. The maximum output speaker system minimizes  
10 destructive sound interference and maximizes coupling  
11 between loudspeakers at low frequencies. The sound-radiating  
12 axes of the individual speaker units are not aimed towards  
13 the chamber exit. Instead, pairs are aimed directly at or  
14 away from each other. This optimizes low frequency  
15 performance without peaking medium-pitch sound. The  
16 manifold chamber exit is smaller than the sum of the  
17 diaphragm areas of the individual speakers inside the  
18 chamber.

1 U. S. Patent No. 3,903,989 teaches a loudspeaker system  
2 that has a cabinet with two compartments, a first of which  
3 contains a low-frequency loudspeaker for producing an omni-  
4 directional radiation pattern, and the second compartment,  
5 above the first, containing a rotationally adjustable  
6 vertically oriented baffle on that are supported additional  
7 loudspeaker motors designed to cover the mid-and high-  
8 frequency bands of the audio frequency spectrum. The baffle  
9 is so shaped and the additional loudspeaker motors located  
10 in positions thereon that they operate as high-efficiency  
11 gradient or dipole loudspeakers over a significant portion  
12 of their respective frequency ranges. The directivity of  
13 the loudspeaker system can be controlled by adjustment of  
14 the position of the baffle relative to the cabinet. It is  
15 conventional in loudspeaker systems to divide the audio  
16 frequency range of interest between a plurality of  
17 individual loudspeaker drivers mounted in a common  
18 enclosure, the higher quality systems utilizing a low

1 frequency driver, or "woofer" for the very low frequencies,  
2 a smaller driver for the lower mid-range of frequencies, a  
3 still smaller driver for upper mid-range frequencies, and  
4 one or more "tweeters" for the high-frequency range. Because  
5 the wavelengths of the mid-and high-frequency signals are  
6 shorter than those of the low frequency signals, the  
7 directivity of the mid- and high-frequency signals of any  
8 particular drive is sharper than that of the low frequency  
9 signals. Accordingly, the sound field produced by an output  
10 signal from a given loudspeaker driver is increasingly  
11 narrower with increase in the signal frequency, with the  
12 consequence that the mid- and high-frequency signals are  
13 severely attenuated in directions offset greater than about  
14 30 degrees to 60 degrees from the central axis of the  
15 loudspeaker array, depending on the dimensions of the driver  
16 and the frequency of the signal. The nature of this problem  
17 is described in detail in a paper by this applicant entitled  
18 "Broadening the Area of Stereophonic Perception" which

1 appeared in the Journal of the Audio Engineering Society,  
2 Vol. 8, No. 2, pp. 91-94 (1960), and a loudspeaker  
3 arrangement representing a solution to the problem is  
4 described and claimed in U. S. Patent No. 3,080,012. The  
5 problem as it applies to quadraphonic reproduction is  
6 described in a paper entitled "Quadrophony Needs Directional  
7 Loudspeakers" which appeared in the March 1973 issue of  
8 Audio Magazine, pages 22, 24, 26 and 30.

9 U. S. Patent No. 4,437,541 teaches a controlled  
10 dispersion loudspeaker configuration in which a loudspeaker  
11 is mounted through a hole in a front baffle forming a seal  
12 between the speaker and the baffle. A rear baffle is  
13 parallelly spaced a predetermined distance away from the  
14 front baffle by means of spacers. Acoustically absorptive  
15 material is placed between the two baffles and is  
16 acoustically open on at least two opposite sides. The sound  
17 waves from the rear of the speaker exit from the acoustic  
18 material and serve to cancel the sound waves at the sides



1 and rear of the loudspeaker configuration emanating from the  
2 front of the speaker. The size of the baffles, as well as  
3 the spacing therebetween, bears a particular relationship to  
4 the frequency of the sound to be reproduced by the  
5 loudspeaker.

6 U. S. Patent 6,130,954 teaches a small, compact  
7 subwoofer cabinet that has openings in two cabinet walls;  
8 first and second cages mounted on respective ones of the  
9 walls in alignment with the openings; a voice coil driven  
10 driver including an annular magnet weighing approximately  
11 225 oz affixed to the first cage; a stationary pole piece  
12 extending through the magnet and defining a magnetic gap  
13 therebetween; a voice coil mounted on a cylindrical voice  
14 coil former positioned within the gap; a cone affixed to one  
15 end of the former; a first flexible surround secured to the  
16 outer end of the cone and to the first cage; a flexible  
17 spider secured to the former and to the first cage; a mass  
18 driven driver including a mass aggregating about 2 lbs; a

1 second flexible surround secured to the mass and to the  
2 second cage; a flexible spider attached to the second cage  
3 and to the mass; both surrounds having a thickness of about  
4 0.1", an edgeroll having a diameter of about 1.5", and  
5 capable of standing off internal pressures of up to about 3  
6 lbs/in.sup.2 ; a drive amplifier capable of delivering up to  
7 about 2,700 watts to a nominal 4 ohm resistive load and  
8 swinging up to about 104 volts for delivering (+).DELTA.v  
9 and (-).DELTA.v drive signals to the voice coil for driving  
10 the voice coil driven driver through a peak-to-peak stroke  
11 of about 2.5" while generating a large back emf sufficient  
12 to counter the applied emf and minimize current flow in the  
13 voice coil.

14 In the field of high fidelity sound reproduction, a  
15 high quality audio system is normally includes a signal  
16 source, a "preamplifier, a power amplifier and a  
17 loudspeaker. The signal source is generally music or  
18 soundtracks from films, compact disk players or laser disk

1 players. The preamplifier receives signals from the signal  
2 source and provides an audio signal to the power amplifier  
3 that amplifies the signal. The loudspeakers can reproduce  
4 the sound from the signal source. Loudspeakers are single  
5 enclosures designed to produce most of the audible frequency  
6 range, which is from 20 Hertz (Hz) to 20,000 Hz. Modern  
7 recording technologies have allowed music and film producers  
8 to make recordings having wider dynamic ranges resulting in  
9 higher signal-to-noise ratios and more extended frequency  
10 response. Many music and film recordings contain more low  
11 frequency information than those of only a few years ago.  
12 This is especially true in film soundtracks, where  
13 recordings of special effects such as explosions are  
14 commonplace. In response to the increased low frequency  
15 sound in recordings, a growing number of audio systems are  
16 adding an additional type of loudspeaker to their existing  
17 array of loudspeakers. This type of loudspeaker is known as  
18 a "subwoofer". Subwoofers are specialized loudspeakers that

1 reproduce only the lowest frequencies of the audible  
2 frequency range meaning those frequencies ranging from  
3 approximately 20 Hz to about 80 to 120 Hz. Reproducing  
4 these low frequency sounds is difficult for the full-range  
5 loudspeakers because the bass drivers for full range  
6 loudspeakers must handle a wider frequency range in that  
7 their frequency response must extend much higher in the  
8 audible frequency range, often to about 2,500 Hz or even  
9 higher depending upon the design of the loudspeaker. Adding  
10 a subwoofer to an audio system relieves the full range  
11 loudspeaker from reproducing the lowest frequencies, thereby  
12 improving its performance. Certain standards are being set  
13 for the reproduction of film soundtracks at home which  
14 require the use of one or more subwoofers. Such standards  
15 include THX (a registered trademark of Lucas Film, Ltd.)  
16 certification from Lucas Film and Dolby AC-3 Surround Sound  
17 (a registered trademark of J. C. Penney Company, Inc.) from  
18 Dolby Laboratories. Dolby AC-3 Surround Sound even has an

1 audio channel dedicated to only low frequency information.  
2 Conventional design of a subwoofer involves the placement of  
3 one or more large bass drivers into a large cabinet--e.g.,  
4 typically a cabinet enclosing a volume of space ranging from  
5 about 8 cubic feet to about 27 cubic feet. Bass drivers,  
6 known as "woofers", generally include a circular "diaphragm"  
7 or "cone" which can be constructed of many different  
8 materials including paper, plastic and kevlar. Woofer cones  
9 have a certain diameter in that bore of the cone is equal  
10 to  $\pi \cdot \text{radius}^2$  ( $\pi \cdot r^2$ ). Subwoofer cones  
11 capable of high acoustic output generally have a diameter of  
12 at least ten inches. The circumference of the cone is  
13 affixed to a "surround," which is a suspension, which is  
14 affixed to the driver's frame. The suspension enables the  
15 cone to move in and out of the driver frame at a particular  
16 frequency and returns it to a null position when no sound is  
17 produced. The peak-to-peak distance traveled by the cone is  
18 known as the "stroke" of the driver--sometimes referred to

1 as the "excursion" of the driver. The drivers installed in  
2 subwoofers have a peak-to-peak stroke or excursion of  
3 between 0.4" and 0.6". Suspensions are constructed of  
4 flexible, compliant materials such as relatively thin  
5 rubber, impregnated cloth, expanded synthetic cellular foam  
6 such, such as expanded cellular polyethylene ("PE") surround  
7 foam, which is compressed to a thickness of about 0.02" and  
8 which is not self-supporting, which have historically  
9 produced very little resistance to peak-to-peak cone  
10 movement, and which are capable of standing off box  
11 pressures of only on the order of nominally about 0.1  
12 lbs/in.sup.2 and, at best, only about 0.15 lbs/in.sup.2.  
13 Movement of the cone about the suspension causes air to be  
14 moved, which is what produces the sound heard and, in the  
15 case of bass, felt by the listener. The amount of air that  
16 can be moved by a driver is directly related to the bore and  
17 stroke of the subwoofer cone. Thus, to increase the amount  
18 of air that a subwoofer can move, the bore, the stroke,

1 and/or both the bore and stroke, can be increased. However,  
2 and as will be discussed below, simply increasing the bore  
3 and/or the stroke has disadvantages. At the center of the  
4 cone, the driver is affixed to the "motor" of the cone that  
5 is comprised generally of a single electrical conductor  
6 placed within a magnetic field. In the prior art, the  
7 electrical conductor is a single electrical wire wrapped  
8 around a cylinder. This arrangement is known as the "voice  
9 coil" of the driver. The voice coil is wrapped around a  
10 voice coil former that is, in turn, affixed to the cone of  
11 the driver and placed in proximity to a magnet. When  
12 current is run through the voice coil, magnetic fields are  
13 created around the voice coil. These voice coil magnetic  
14 fields interact with the magnetic fields of the magnet,  
15 which causes the voice coil former to move. Movement of the  
16 voice-coil former causes the movement of the cone. Movement  
17 of the cone causes movement of air. The movement of air  
18 produces sound. Producing sound at higher volumes requires

1 greater movements of the cone. Greater movements of the  
2 cone are produced when the voice coil and the magnet of the  
3 driver have greater magnetic field interactions. This  
4 increased magnetic field interaction is produced when the  
5 voice coil has more current running through it. To  
6 reproduce low frequencies at high volume levels, a subwoofer  
7 must be capable of moving large quantities of air. A  
8 subwoofer for use in the home can move approximately one-  
9 hundred thirty cubic inches of air. For louder audio  
10 volumes, it is desirable that the subwoofer be capable of  
11 moving even more air, such as one hundred eighty cubic  
12 inches of air. A cone of a fifteen inch diameter woofer has  
13 a diameter of approximately thirteen inches and a stroke of  
14 approximately 0.6 inches. This woofer can move  
15 approximately eighty cubic inches of air. The subwoofer  
16 will utilize two of these drivers because two drivers are  
17 able to move approximately one hundred sixty cubic inches of  
18 air. One disadvantage of having a driver with a fifteen



1 inch cone is that it is difficult to design a cone of that  
2 size which is rigid enough to resist distortion when the  
3 cone has such a large surface area.

4 Another subwoofer utilizes four twelve-inch drivers.  
5 The cone of each driver has a diameter of approximately ten  
6 inches and a stroke of approximately 0.6 inches. This  
7 subwoofer can move approximately one hundred ninety cubic  
8 inches of air, but suffers from the disadvantage that four  
9 drivers are required thereby greatly not only increasing the  
10 size of the cabinet required, but also adding both cost and  
11 weight. It is possible to increase the stroke of the driver  
12 thereby increasing the amount of air that is moved by the  
13 driver. When the stroke of the driver is increased, the  
14 efficiency of the driver is substantially reduced because  
15 less of the voice coil will remain in the magnetic gap.

16 These subwoofers invariably require a large cabinet.  
17 One reason that many prior art subwoofers utilize several  
18 large drivers is so that they can move enough air for

1 adequate performance. Large cabinets are necessary for  
 2 these subwoofers for reasons having nothing to do with the  
 3 number of drivers installed therein. Drivers for subwoofers  
 4 are generally installed in a sealed or vented box. When the  
 5 cone of the driver moves, it must overcome the forces  
 6 inherently created because of the box structure itself. For  
 7 instance, during operation, if the cone is moving into the  
 8 cabinet, it compresses the air inside the cabinet thereby  
 9 creating a force resisting inward cone movement. If, on the  
 10 other hand, the cone is moving out of the cabinet, it  
 11 creates a vacuum that exerts a force tending to pull the  
 12 cone back into the cabinet. These conditions exist for both  
 13 sealed and vented boxes or cabinets. Atmospheric pressures  
 14 outside the cabinet also affect these forces. The driver  
 15 must overcome the foregoing forces during movement of the  
 16 cone. The higher the pressure to be overcome (whether  
 17 positive or negative) means that the more power that is  
 18 required to overcome that pressure. The physical structure

1 of the subwoofer can be manipulated to deal with the  
 2 increase in power that is required to overcome the foregoing  
 3 forces. First, a larger enclosure can be used. A larger  
 4 enclosure will create less resistance to inward and outward  
 5 cone movements because it contains more air than a smaller  
 6 enclosure. The reason for this is that when the driver cone  
 7 moves into the cabinet, the larger air volume is compressed  
 8 to a lower pressure. Less power is required by the voice  
 9 coil to overcome the forces created by the compression of  
 10 air within the cabinet. When the cone of the driver moves  
 11 out of the cabinet, it creates less vacuum which therefore  
 12 allows the voice coil to move the cone with less power.  
 13 These subwoofers have utilized relatively large cabinets.

14 A second design factor is related to the stroke of the  
 15 driver. If the stroke of the driver is short, the cone of  
 16 the driver will have physical limitations on how far it can  
 17 enter into the cabinet and how far it can extend outwardly  
 18 from the cabinet. The shorter the extension of the driver

1 cone into the cabinet means that the less air that will be  
 2 compressed within the cabinet. Such a movement will require  
 3 less power into the voice coil to effectuate movement of the  
 4 cone. The same holds true for extension of the cone out of  
 5 the cabinet. The shorter the extension of the cone of the  
 6 driver out of the cabinet, it will create less of a vacuum  
 7 so that less power that will be required for movement of the  
 8 cone.

9 A power amplifier may provide power to a subwoofer. A  
 10 subwoofer may use a separate power amplifier. However, for  
 11 ease of packaging, a subwoofer may alternatively utilize a  
 12 power amplifier that is built into the cabinet of the  
 13 subwoofer. The power amplifier is capable of creating  
 14 between one hundred to three hundred watts of power. Large  
 15 amounts of power are required to drive the subwoofer for  
 16 many of the reasons described above. A power amplifier  
 17 capable of providing such power levels tends to create large  
 18 amounts of heat that, in turn, requires large heat sinks,

1 massive power reserve capacitors and large transformers all  
2 of which are large in size, heavy, and expensive. All of  
3 these factors are undesirable and tend to reinforce the need  
4 for a relatively large cabinet.

5       As can be seen from the foregoing, because of the large  
6 power demands required by a subwoofer and the large cost  
7 involved in providing large amounts of power amplification,  
8 the subwoofer has invariably required the use of a large  
9 cabinet which has held a driver having a large diameter and  
10 a short stroke. Such an arrangement allowed the subwoofer  
11 to move reasonable amounts of air without distortion.

12 Normal listening environments often do not have space for  
13 such a large cabinet. Therefore, there is a need for a  
14 subwoofer system capable of producing low frequency  
15 information at high listening volumes that is packaged in a  
16 small volume cabinet. For many years the design of audio  
17 woofers has been predicated on conventional wisdom commonly  
18 referred to as "Hoffman's Iron Law" which provides:

1  $\text{Eff.} = V_{\text{sub.BOX}} / f_{\text{sub.0}}^3 = k V_{\text{sub.BOX}} / f_{\text{sub.0}}^3$  [1]

2 where  $f_{\text{sub.0}}$  is the desired low frequency cutoff or limit

3 for the subwoofer;  $V_{\text{sub.BOX}}$  is the volume of the cabinet;

4 and,  $\text{Eff.}$  is the efficiency of the subwoofer.

5 Unfortunately, if one wishes to reduce the low frequency

6 cutoff ( $f_{\text{sub.0}}$ ) from, for example, 50 Hz to 18 Hz while

7 retaining the same efficiency, the volume of the woofer

8 cabinet must be significantly increased. Or, if one wishes

9 to decrease box volume from, for example, 1 cubic foot to

10 0.4 cubic foot and, at the same time, decrease the low

11 frequency cutoff ( $f_{\text{sub.0}}$ ) from, for example, 50 Hz to 18

12 Hz, efficiency drops by a factor of approximately 53.

13 Consequently, the woofer designer finds that where a 50 watt

14 or 100 watt amplifier might have operated a 1 cubic foot

15 woofer at a 50 Hz low frequency cutoff, a 0.4 cubic foot box

16 at 18 Hz low frequency cutoff will require an amplifier that

17 is approximately 53 times larger than conventional. A

18 loudspeaker in a 1 cubic foot box with a low frequency

1 cutoff of 50 Hz and one percent (1%) efficiency will  
2 normally operate satisfactorily if it employs a 200 watt  
3 amplifier. If a designer arbitrarily decides to reduce the  
4 box volume to 0.4 cubic foot and lower the frequency cutoff  
5 to 18 Hz, the wattage requirement for the amplifier would be  
6 10,600 watts. This would be ludicrous and is neither  
7 practical, cost effective nor economically feasible from a  
8 commercial standpoint. In essence, Hoffman's Iron Law  
9 forbids one from making a subwoofer having a small volume  
10 box, high efficiency and low frequency cutoff. Designers of  
11 subwoofers have not deviated from religious adherence to  
12 such theories. If the designer wants to have a highly  
13 efficient bass driver for a highly efficient woofer that can  
14 have a very low frequency cutoff, the box must be huge.  
15 Conversely, if the designer wishes the box to be small,  
16 there has heretofore been no way to get a lot of bass out of  
17 it, either low or loud, with high efficiency. At the same  
18 time, speaker designers have been taught, and have believed,

1 that there is an optimum size for magnets employed in voice  
 2 coil driven woofers. It has been assumed that if the magnet  
 3 is too small, the speaker will not work at all, but if the  
 4 magnet is too large, only a small percentage of the output  
 5 wattage from the power amplifier will be applied to the  
 6 voice coil. Consequently, the designers have concluded that  
 7 an optimum magnet must lie somewhere between "too small" and  
 8 "too large" in order to produce effective power in the voice  
 9 coil. Virtually all subwoofers will employ a magnet that  
 10 weighs on the order of only about 20 ounces or less. Even  
 11 in the face of today's highly advanced technologies, speaker  
 12 designers still believe that a well designed, commercially  
 13 marketable subwoofer should employ a relatively large  
 14 cabinet that is from about eight to about twenty-seven cubic  
 15 feet, multiple large drivers, drivers with peak-to-peak  
 16 strokes generally on the order of not more than 0.4 inch to  
 17 0.6 inch, magnets weighing, on average, not more than 20  
 18 ounces and, at the very most, about 40 ounces; low internal



1 box pressures of on the order of only about 0.1 pounds per  
2 square inch and surrounds that are very compliant leading to  
3 surrounds that are, at best, flimsy and incapable of  
4 supporting the components of a moving driver without wobble  
5 and consequent degradation of the audio sounds generated.  
6 The problem of attempting to design a woofer which is small  
7 in size and defining an enclosed volume of space of about  
8 0.4 cubic foot to about 0.5 cubic foot having a low cutoff  
9 frequency below about 40 Hz, and which is, at the same time,  
10 efficient, has defied solution. Louis D. Fielder of  
11 Dolby Laboratories, Inc. and Eric M. Benjamin have stated in  
12 an article entitled "Subwoofer Performance for Accurate  
13 Reproduction of Music", J. Audio Eng. Soc., Vol. 36, No. 6,  
14 June 1988, pages 443 through 454 at page 446: "For the  
15 required value of 0.0316 acoustic watts at 20 Hz, this  
16 results in a volume excursion of 41.8 cubic inches. For a  
17 single 12 inch woofer [effective piston diameter 10 inches  
18 this would require a peak linear excursion of 0.53 inch.

1 This large excursion requirement can be reduced by using  
2 larger drivers, increasing the number of drivers and  
3 utilizing the low-frequency boost provided by the room.  
4 With four 15 inch woofers the peak linear excursion required  
5 is 0.078 inch, neglecting room effects." In short, the  
6 "solution" advocated by the authors, who are accredited  
7 experts that were then attempting to establish design  
8 criteria for the performance of subwoofers to be used for  
9 the reproduction of music in the home, is to design a woofer  
10 having a peak linear excursion of 0.53 inch, to attempt to  
11 reduce this "large excursion" of 0.53 inch by using larger  
12 drivers and increasing the number of drivers and the size of  
13 the box or subwoofer cabinet, and utilizing the low  
14 frequency boost provided by the listening room. Those  
15 skilled in the art relating to subwoofers will recognize  
16 that the efficiency of a subwoofer is proportional to the  
17 size of the box or cabinet that the subwoofer is mounted in.  
18 Therefore, a box or cabinet that is 1/10th the size of a

1 conventional subwoofer box or cabinet would ordinarily be  
 2 ten times less efficient than its counterpart. Under those  
 3 circumstances, ten times more heat is developed in the voice  
 4 coil regardless of the efficiency of the driving amplifier.  
 5 Consequently, the voice coil will soon overheat and that has  
 6 been a major stumbling block to the development of very  
 7 small, but powerful, subwoofers. A subwoofer may be  
 8 characterized by its high efficiency and, at the same time,  
 9 its extremely small box or cabinet. The broad concept flies  
 10 in the face of all known subwoofer computer modeling  
 11 programs as well as the teachings in the literature. In  
 12 this connection, those skilled in the art will appreciate  
 13 that raw driver efficiency is expressed as:  
 14  $Eff. = (Bl)^2 / r_{sub.e} [2]$  where "B" is the magnetic field  
 15 strength, and "l " and "r.sub.e " are constants.  
 16 Rewriting equation [2] it is found:  $Eff. = kB_{sup.2} [3]$   
 17 Based upon the foregoing, those skilled in the art will  
 18 understand that in a subwoofer driver where B is increased

1 by a factor of 3.3, the efficiency will be increased by a  
2 factor of approximately 10. Unfortunately when such a  
3 subwoofer driver is built and installed in a box bass output  
4 is found to be actually far less than before the magnetic  
5 field was increased. This fact is well known to those  
6 skilled in the subwoofer art so that subwoofers have evolved  
7 with magnetic fields optimized for maximum bass output.  
8 Subwoofers designed with magnets optimized for maximum bass  
9 output are very inefficient. The reason for this is because  
10 the motor of the subwoofer is operating very close to stall,  
11 a condition characterized by relatively high armature  
12 winding and heating. By increasing the magnetic field  
13 strength, the efficiency is increased, but the bass output  
14 is decreased because of the large back emf generated by the  
15 motion of the voice coil of subwoofer immersed in its  
16 magnetic field. The magnitude of the back emf is  
17 established by Lenze's Law:  $\text{back emf} = d\phi/dt$ , [4] where  
18  $\phi$  is the magnetic flux. The back emf generated acts to

1 prevent current from flowing in the voice coil because it  
 2 opposes the forward voltage impressed on the voice coil  
 3 winding. With the lowered current in the voice coil, the  
 4 result is less bass. It must be recognized at this point  
 5 that all literature known to the inventor, the descriptive  
 6 equations therein and all subwoofer computer modeling  
 7 programs based on the literature make the basic assumption  
 8 that the subwoofer is operating in stall in order to  
 9 simplify the modeling. This assumption has been tenable  
 10 because a tracking down converter drive amplifier able to  
 11 deliver the high voltage necessary to overcome the back emf  
 12 did not exist. Subwoofer designers have all made the  
 13 simplifying assumption that the back emf at system impedance  
 14 minimums is not significant. Another major problem  
 15 encountered by subwoofer designers is directly related to  
 16 the fact that subwoofers are exceptionally prone to hum  
 17 problems induced by power line "ground loops". Ground loops  
 18 are caused by a redundant ground that runs from the wall

1 plug or other suitable alternating current source where the  
2 subwoofer is plugged in, through the power line to where the  
3 audio signal source, such as a CD player, an F.M. tuner or a  
4 turntable, is plugged into the power line and back to the  
5 subwoofer audio input through the audio cable shields. This  
6 constitutes a loop called a "ground loop" generates a very  
7 undesirable 60 Hz hum. Subwoofers all suffer from unwanted  
8 "ground loop" induced 60 Hz hum to a greater or lesser  
9 degree. Subwoofer designers have attempted to solve the  
10 "ground loop" induced 60 Hz hum problem in various ways.  
11 One proposed solution includes the use of a balanced  
12 transformer that breaks the loop by virtue of its primary  
13 and secondary windings. The transformer can either be at  
14 the power line input (power transformer), or at the audio  
15 input (input transformer), or, for that matter, at both  
16 locations. Another attempted solution involves the use of  
17 optical couplings in which the audio signal is coupled by a  
18 light beam in that there is no ground connection. Both of

1 the foregoing approaches have been effective in  
2 substantially reducing, but not eliminating, "ground loop"  
3 induced 60 Hz hum problems. This is because while they  
4 effectively "break" the ground(s), they do not suppress the  
5 hum voltage generated across the broken ground or grounds.

6 The suspension system in any loudspeaker normally  
7 includes a surround and a spider. The surround is a front  
8 or outer suspension. The spider is a rear suspension. The  
9 surround is the mechanical device and holds the outer edge  
10 of the diaphragm/cone of the loudspeaker. Often the word  
11 "roll" is used in place of "surround" when describing the  
12 front suspension. Surrounds can be constructed from several  
13 materials including rubber, compressed foam rubber  
14 (neoprene), corrugated cloth, paper and plastic. Roll  
15 surrounds have a single, large, semi-circular corrugation  
16 typically constructed from rubber, compressed foam rubber or  
17 treated fabric.

18 Surrounds help keep the cone centered and provide a





1 limits. Larger surrounds cannot be used without an  
2 attendant loss in effective cone area for a loudspeaker of  
3 given outside diameter, thus, creating an inevitable trade-  
4 off. Excursion and cone-area are the two factors which  
5 contribute to a loudspeaker's volume displacement. The  
6 higher the volume displacement capability of a loudspeaker,  
7 the greater the ultimate low frequency output potential of  
8 the loudspeaker can be. In addition to controlling the  
9 linear motion of the cone, the surround also acts as a major  
10 centering force for the loudspeaker's voice coil. This  
11 centering force prevents the voice coil and former from  
12 rocking and rubbing against the pole piece or top plate.

13       The surround is typically glued to the inner top edge  
14 of a flat extension or rim on the outside of the frame of  
15 the loudspeaker. The frame also acts as the mounting flange  
16 of the loudspeaker. A significant amount of cone-area is  
17 sacrificed, relative to the loudspeaker's overall footprint  
18 (outside diameter). The cone-area is a major contributing

1 factor to a loudspeaker's output and efficiency. The  
2 sacrifice in cone-area is seen as a necessary evil because  
3 of the need to provide an accessible mounting flange for the  
4 loudspeaker.

5       Current methods for replacing moving parts of a cone  
6 loudspeaker, for the purpose of repair, require special  
7 skill, tools and adhesives. Typically, the moving parts are  
8 cut away and the loudspeaker frame and motor structure  
9 (magnet and metal parts that complete the magnetic circuit)  
10 are stripped down with chemicals or hand scraped to remove  
11 adhesive residue. Once the frame is stripped, new moving  
12 parts must be glued together, aligned carefully and glued to  
13 the loudspeaker frame. This repair or replacement assembly  
14 process normally is handled by trained loudspeaker  
15 technicians and requires specialized gauges or alignment  
16 spacers for each loudspeaker, as well as a high degree of  
17 precision in order to be successful. Some current small  
18 dome loudspeakers, primarily tweeters, and compression

1 drivers feature the ability to quickly remove and replace  
 2 their moving parts. This is facilitated greatly in these  
 3 designs due to the lack of a rear suspension or spider. In  
 4 these designs, the diaphragm, voice-coil and surround are  
 5 typically attached to a rigid frame that bolts or screws to  
 6 the top plate of the loudspeaker. The frame is usually  
 7 located with holes that line up to pegs on the motor  
 8 structure for alignment. In such designs, the loudspeaker  
 9 must be removed from its mounting location to perform the  
 10 repair. One product currently on the market provides a  
 11 woofer in which the motor structure (i.e. magnet, back  
 12 plate, pole piece and top plate) is removed from the frame  
 13 so that the voice coil can be inspected. However, the moving  
 14 parts (roll, cone body, dust cap, voice coil and spider)  
 15 remain attached to the loudspeaker's frame. Another product  
 16 on the market provides a cone loudspeaker that features a  
 17 screw-down spacer between its dual spiders or rear  
 18 suspensions. The spacer screws through the frame to the top

1 plate of the loudspeaker. The screws do not provide the  
 2 necessary physical constraints to align the voice coil  
 3 within the magnetic gap. This is still done with gauges  
 4 (alignment spacers). The surround is glued to the frame in  
 5 a conventional manner and the spider is glued to the spacer.  
 6 This product fails to provide for easy field replacement of  
 7 its parts. A loudspeaker must be carefully optimized for  
 8 its intended task. Changes in its moving mass, motor  
 9 strength, voice coil winding length/ gauge/thickness or  
 10 suspension compliance radically affect the performance of  
 11 the loudspeaker. There are inevitable tradeoffs in the  
 12 process of loudspeaker design. These tradeoffs must be  
 13 carefully balanced with the intended task of the loudspeaker  
 14 in mind, concert sound reinforcement, automotive sub-bass, a  
 15 home-theater. With woofers, the intended enclosure type  
 16 affects the design of the driver as well. An end user  
 17 chooses a loudspeaker that works best in his intended  
 18 application. The most expensive components of a loudspeaker

1 are its non-moving parts, which generally include the  
2 loudspeaker frame and the motor structure. The moving parts  
3 of the loudspeaker generally represent a smaller portion of  
4 the total cost of the loudspeaker. If the user's operating  
5 conditions change, the loudspeaker may no longer be well-  
6 suited and is likely to be replaced with a more appropriate  
7 loudspeaker. Such is the case even if there is nothing  
8 wrong with the original loudspeaker and usually amounts to a  
9 relatively significant expenditure each time the operating  
10 conditions change. Some existing small dome loudspeakers,  
11 primarily tweeters, and compression drivers feature the  
12 ability to remove and replace their moving parts, in the  
13 event of failure. Different impedance diaphragms are  
14 offered that will work in the same motor structure. The  
15 basic mission of the loudspeaker is not changed, only the  
16 load presented to the amplifier. However, the prior art  
17 fails to provide for reconfiguring the same motor structure  
18 in the field for different applications and enclosure types,

1 specifically for low frequency woofers. Additionally, the  
2 prior art fails to provide for a loudspeaker design that  
3 provides for relatively quick field replacement of the  
4 moving parts of a cone type loudspeaker, and in more  
5 particular to cone type loudspeakers which feature a rear  
6 suspension or spider in addition to the surround. The prior  
7 art also fails to provide a surround that is attached to the  
8 outer edge of the loudspeaker frame for improved overall  
9 displacement capability. Furthermore, the prior art fails  
10 to provide for a removable surround. It is therefore, to the  
11 effective resolution of the aforementioned problems and  
12 shortcomings of the prior art that the present invention is  
13 directed.

14 U. S. Patent No. 4,433,214 teaches an electro-dynamic  
15 acoustic transducer with a slotted piston suspension system.  
16 Use of the slotted piston suspension results in greater  
17 linear excursions by relieving stresses within the diaphragm  
18 during the movement and allows operation of a transducer

1 with greater magnet size and greater radiating areas of  
2 diaphragm suspension thereby improving overall efficiency of  
3 the transducer. The slotted piston suspension can be  
4 utilized with electro-dynamic acoustic transducers operating  
5 in the range of 200 to 20,000 cycles per second.

6 The piston suspension assemblies of many different  
7 shapes have been devised for use in cone displacement  
8 electro-dynamic acoustical transducers containing permanent  
9 magnets in order to provide the electromagnetic fields  
10 required for operation. Small acoustical transducers are  
11 inexpensive and are typically found in portable two-way  
12 radio communications devices or personal electronic radio  
13 receiving apparatus. In order to allow adequate expansion  
14 of the sound-radiating dome, which will result in improved  
15 linear excursions during operation, small electro-dynamic  
16 acoustic transducers require much larger piston suspensions  
17 than exist today. The piston suspension assemblies are  
18 often fraught with many different types of stresses that

1 occur at different positions within the plane of the sound  
 2 radiating dome and piston suspension during cone  
 3 displacement. One such stress is a "bending" stress that  
 4 occurs along the circumference of the sound radiating dome  
 5 at the junction of the piston suspension. A second stress  
 6 is found stretching along a plane, perpendicular to the  
 7 radii of the piston suspension, in the sound-radiating dome.  
 8 During operation, these stresses result in continued wear  
 9 and tear of the piston suspension and sound-radiating dome,  
 10 thereby causing a decrease in the performance of the  
 11 transducer in its ability to produce linear excursions  
 12 during operation. This will result in the acoustical  
 13 transducer becoming less and less effective as operation  
 14 continues over a period of time.

15 The piston suspensions often utilize arcuate slots  
 16 contained within a flat (not curved) piston suspension.  
 17 Generally, these slots, while relieving some of the stresses  
 18 discussed above, create "bending" type stresses elsewhere in



1 the piston suspension (i.e. in the material between the  
2 slots) and concentric "stretching" type stresses within the  
3 arcuate slots of the flat suspensions, which occur by the  
4 twisting motion of the sound radiating dome or cone during  
5 its displacement. The piston suspensions of acoustical  
6 transducers are generally made from any varied materials and  
7 from a material different from that which the sound-  
8 radiating dome is made. The resiliency of such materials is  
9 varied, which affects the linearity of the resulting  
10 excursions. This difference in material will introduce an  
11 additional cost in the manufacturing of the end product.  
12 The sound-radiating dome of an acoustical transducer is  
13 smaller in size for a given linear excursion, than the  
14 sound-radiating dome associated with the piston suspension.  
15 The piston suspension assembly for an electro-dynamic  
16 acoustical transducer will result in increased efficiency  
17 and improved audio quality. The acoustical transducer  
18 piston suspension assembly produces linear excursions

1 corresponding to much larger piston suspension assemblies  
 2 that exist in larger electro-dynamic transducers, thus  
 3 allowing the surface area of the sound radiating dome and  
 4 the size of the magnet to be increased, which will improve  
 5 the efficiency of the transducer. The piston suspension  
 6 assembly for a small acoustical transducer has a center  
 7 sound radiating dome of which at least 80% of the total  
 8 surface area of the suspension and dome thereby allowing the  
 9 use of magnets which are physically larger in size than  
 10 those presently used in the same-sized electro-dynamic  
 11 transducers. An electro-dynamic transducer has a piston  
 12 suspension assembly made of a resilient plastic film to  
 13 allow the surface area of the piston suspension to be  
 14 sharply curved. A sound radiating dome and piston  
 15 suspension assembly has been fabricated from a unified piece  
 16 of resilient plastic film, which simplifies production and  
 17 reduces costs.

18 A small electro-dynamic acoustical transducer includes a

1 piston suspension assembly which is sharply curved around  
2 the circumference of the center-positioned sound radiating  
3 dome and has elongated stress relieving slots integral to  
4 the surface thereof, such piston suspension being made from  
5 a resilient, flexible plastic film. An increase in the size  
6 of the over-all piston suspension will result in a  
7 proportional increase in the linear excursions of the sound-  
8 radiating dome, thereby increasing the overall performance  
9 of the transducer during operation. For the same required  
10 excursion produced by existing electro-dynamic acoustical  
11 transducers in the prior art, the piston suspension of the  
12 present invention can be made smaller in size. In this  
13 manner, the radiating area and magnet size of the electro-  
14 dynamic transducer can be maximized which will improve the  
15 operating efficiency of the transducer. The piston  
16 suspension assembly is for use with an associated electro-  
17 dynamic acoustical transducer.

18 The slotted piston suspension assembly includes a

1 curved centered sound radiating dome and a curved piston  
 2 suspension manufactured from the same single piece of  
 3 resilient flexible plastic material. Similar materials,  
 4 which can be sharply curved, may also be used. The curved  
 5 piston suspension further includes stress-relieving  
 6 elongated slots integral therein. The slots are positioned  
 7 at predetermined intervals along the circumference of the  
 8 upper surface of the piston suspension. The elongated slots  
 9 have a predetermined reduced thickness relative to the  
 10 thickness of the material of the surrounding piston  
 11 suspension thereby preventing air that is activated in front  
 12 of the sound-radiating dome from moving to the back sonic  
 13 area which would normally result in sound cancellation. The  
 14 slotted piston suspension assembly causes the simultaneous  
 15 relief of certain bending stresses experienced along the  
 16 radii of the sound radiating dome, as well as certain  
 17 perpendicular concentric stresses, in such a manner as to  
 18 enhance the overall effectiveness and the overall efficiency

1 of the transducer. The slotted piston suspension is  
 2 designed for use in the range of 200 to 20,000 cycles per  
 3 second and has been tested and found to be highly  
 4 satisfactory in use. Other piston suspensions for  
 5 acoustical transducers customarily found create a number of  
 6 different types of stresses during their cone displacement.  
 7 One such stress is the "bending" stress along the radii of  
 8 the suspension. Another stress, which is created during  
 9 operation, is a "stretching" stress that is perpendicular to  
 10 the radii of the suspension in the plane of the sound-  
 11 radiating dome. There will exist certain concentric  
 12 stretching stresses in the strips between the slots.  
 13 Concentric arcuate slots in the plane of a flat cone are  
 14 introduced. These slots will relieve bending stresses along  
 15 the radii of the piston suspension, they will create bending  
 16 stresses in the strips between the slots and create other  
 17 concentric stretching stresses when the sound radiating dome  
 18 twists during resulting displacement. This twisting motion

1 is nonlinear and undesirable.

2 U. S. Patent No. 5,949,898 teaches a surround for a  
3 loudspeaker assembly. The outside edge of the surround is  
4 attached to the outer edge of the frame of the loudspeaker  
5 via a permanent or removable means. When removably  
6 attached, access to the mounting holes of the frame of the  
7 loudspeaker is accomplished by moving the roll to one side,  
8 prior to the attachment of the securing means. The method of  
9 attachment may include either the use of an annular o-ring  
10 or the use of a locking finger.

11 U. S. Patent No. 5,734,734 teaches a voice coil adaptor  
12 ring and loudspeaker system of the moving coil type. The  
13 loudspeaker system includes a cone diaphragm supported by a  
14 frame, a voice coil former for supporting a voice coil, and  
15 a lower suspension for securing and centering the voice coil  
16 former in a magnetic gap while it is displaced by a magnetic  
17 circuit. The voice coil adaptor ring is mounted over the  
18 voice coil former and includes a substantially cylindrical

1 sleeve which has a ledge extending outward from the sleeve  
2 for supporting the cone and lower suspension. An inner glue  
3 flange projects inward from the sleeve so as to define a  
4 diameter corresponding to an outer diameter of the voice  
5 coil former. The sleeve, the inner glue flange and the  
6 voice coil former define a gap for receiving epoxies. A  
7 plurality of venting passages are in fluid communication  
8 with a cap volume defined by the cone and a dust cap for  
9 venting hot air from the cap volume.

10 U. S. Patent No. 6,224,801 teaches a method of making a  
11 speaker that includes providing a pair of dies. The dies  
12 between them define a cavity. A first portion of the cavity  
13 receives a diaphragm of the speaker. A second portion of  
14 the cavity adjacent an outer perimeter of the diaphragm  
15 receives a fluid thermoplastic elastomer for forming a  
16 diaphragm surround. The second portion includes a  
17 perimetally inner first region adjacent the outer perimeter  
18 of the diaphragm for receiving the thermoplastic elastomer

1 to form a perimetrally inner flange for bonding to the  
 2 diaphragm adjacent the outer perimeter of the diaphragm.  
 3 The second portion includes a central second region for  
 4 receiving the thermoplastic elastomer to form a connecting  
 5 arch of the surround. The second portion also includes a  
 6 perimetrally outer third region for receiving the  
 7 thermoplastic elastomer to form a perimetrally outer flange  
 8 for attachment to a diaphragm support. A diaphragm is placed  
 9 between the dies. The dies are closed. An amount of the  
 10 fluid thermoplastic elastomer sufficient to fill the second  
 11 portion is introduced into the cavity, and is permitted to  
 12 solidify. This invention relates to transducers and  
 13 particularly to a method of making a loudspeaker and a  
 14 loudspeaker made by the method.

15  
 16

17 U. S. Patent No. 3,997,023 teaches an injection-molded  
 18 surround that attached to a speaker frame and a diaphragm by



1    suitable adhesives.

2            U. S. Patent No. 5,319,718 teaches a diaphragm that is  
 3    provided with a closed-cell polyurethane foam surround by  
 4    placing the diaphragm in a mold, depositing uncured foamable  
 5    urethane around the perimeter of the diaphragm, closing the  
 6    mold and permitting the foamable urethane to foam and cure  
 7    in a cavity formed by the mold around the perimeter of the  
 8    diaphragm. The urethane impregnates the exposed outer  
 9    peripheral edge of the diaphragm, bonding it to the  
 10   diaphragm, and forms a closed cell outer skin as it cures.

11           A method of making a speaker includes providing a pair  
 12   of dies that defines between them a cavity. A first portion  
 13   of the cavity is for receiving a diaphragm of the speaker.  
 14   A second portion of the cavity adjacent an outer perimeter  
 15   of the diaphragm when it is placed in the cavity receives a  
 16   fluid thermoplastic elastomer for forming a diaphragm  
 17   surround. The second portion includes a perimetrally inner  
 18   first region adjacent the outer perimeter of the diaphragm

1 for receiving the thermoplastic elastomer to form a  
2 perimetrally inner flange for bonding to the diaphragm  
3 adjacent the outer perimeter of the diaphragm when the fluid  
4 thermoplastic elastomer is introduced into the cavity. The  
5 second portion includes a central second region for  
6 receiving the thermoplastic elastomer to form a connecting  
7 arch of the surround when the fluid thermoplastic elastomer  
8 is introduced into the cavity.

9 The second portion also includes a perimetrally outer  
10 third region for receiving the thermoplastic elastomer to  
11 form a perimetrally outer flange for attachment to a  
12 diaphragm support when the fluid thermoplastic elastomer is  
13 introduced into the cavity. A diaphragm is placed between  
14 the dies. The dies are closed. An amount of the fluid  
15 thermoplastic elastomer sufficient to fill the second  
16 portion is introduced into the cavity, and is permitted to  
17 solidify.

18 U. S. Patent No. 6,219,432 teaches a loudspeaker drive

1 unit. The driver unit includes a diaphragm, a chassis  
2 member and a surround. The surround connects the outer  
3 portion of the diaphragm to the chassis member so that  
4 substantially all parts of the surround located between the  
5 diaphragm and the chassis member and capable of radiating  
6 sound are arranged parallel or at an acute angle with  
7 respect to the longitudinal axis of the loudspeaker drive  
8 unit, or the surround is made of a body of foam material  
9 arranged to be compressed against the chassis member when  
10 the diaphragm moves towards the chassis member, or the  
11 bending wave impedance of the surround is matched to the  
12 bending wave impedance of the diaphragm.

13 Known loudspeaker drive units include a diaphragm of  
14 which the outer portion is connected to a chassis member by  
15 way of a flexible surround.

16 U. S. Patent No. 6,118,884 teaches a loudspeaker system  
17 of the moving coil type which includes a cone diaphragm  
18 supported by a frame, a voice coil former for supporting a

1 voice coil, a lower suspension for securing and centering  
2 the voice coil former in a magnetic gap while it is  
3 displaced by a magnetic circuit and a voice coil adaptor  
4 ring. The voice coil adaptor ring is mounted over the voice  
5 coil former and includes a substantially cylindrical sleeve  
6 having at least one ledge extending outward from said sleeve  
7 for supporting the cone and lower suspension and a plurality  
8 of venting passages in fluid communication with a cone  
9 volume defined by the cone for venting hot air from the cone  
10 volume.

11 U. S. Patent No. 5,111,510 teaches a speaker which  
12 includes a diaphragm integrally combined with a first frame  
13 piece and a driver unit integrally combined with a second  
14 frame piece.

15 U. S. Patent No. 5,371,805 teaches a speaker which  
16 employs a diaphragm secured to a first periphery of an edge  
17 member and a frame secured to a second periphery of the edge  
18 member.

1           U. S. Patent No. 5,323,469 teaches a conical  
2   loudspeaker which has a conical stabilizing element joined  
3   between an underside of a speaker membrane and an outside  
4   surface of a speaker moving coil carrier.

5           U. S. Patent No. 5,424,496 teaches an electromagnetic  
6   converter. The converter includes an internal magnet  
7   system, a moving coil and tubular segment.

8           U. S. Patent No. 4,764,968 teaches a disk-like  
9   diaphragm made from a conical plastic film and provided with  
10   vacuum formed support members which extend up to the disk-  
11   like radiating layer.

12          U. S. Patent No. 4,118,605 teaches a coil mount  
13   structure which includes a cylindrical member, around one  
14   end portion of which a diaphragm edge is fixed, an inner  
15   peripheral edge portion where a damper is removably fixed,  
16   and an opposite end portion around which a coil is provided.  
17   Kobayashi does not provide any structure for ventilating air  
18   pressure from beneath the dust cap or a structure for

1 creating a secure joint between the diaphragm/cone, spider,  
 2 and/or voice coil. The structure of an adaptor-ring  
 3 facilitates a stronger adhesive joint between the cone,  
 4 spider, a voice coil bobbin and a means for venting air  
 5 pressure buildup. There remains a need for a loudspeaker  
 6 capable of providing improved structural joints between the  
 7 speaker cone, spider, and voice coil former, allowing the  
 8 use of smaller voice coil systems and providing ventilation  
 9 in the speaker without forfeiting performance.

10 An acoustical piston suspension includes the curvature  
 11 of a resilient sound radiating dome and the uniform  
 12 recurring elongated stress relieving slots in the outer  
 13 circumference of the upper surface of the curved piston  
 14 suspension. This piston suspension assembly is manufactured  
 15 from a single piece of resilient plastic material or from  
 16 materials of similar resiliency. A reinforcing plastic film  
 17 may be permanently affixed to the sound radiating dome to  
 18 provide the necessary rigidity required for greater linear

1 excursions in the radiating area and overall optimum  
2 effectiveness. The elongated stress-relieving slots are  
3 specifically designed to relieve those stresses created  
4 which are perpendicular to the radii of the suspension  
5 (along the concentric circles). This will leave only the  
6 bending-type stresses remaining, which lie along the radii  
7 of the suspension in the material between the slots.  
8 To enhance the resiliency and responsiveness of the piston  
9 suspension during operation, the reinforcing plastic film  
10 does not interfere with the curved piston suspension, i.e.  
11 elongated stress-relieving slots and the resilient material  
12 between the elongated slots. A single piece of resilient  
13 plastic material is utilized to make the curved sound  
14 radiating dome and the curved piston suspension structure in  
15 the improved acoustical transducer. The residual material  
16 within the elongated stress-relieving slots, which are  
17 incorporated in the outer circumference of the upper surface  
18 of the piston suspension, will prevent the activated air

1 from moving from the front of the diaphragm to the rear of  
2 the sonic area that would result in sound cancellation.  
3 This material within the elongated stress-relieving slots  
4 has a predetermined thickness that is less than the  
5 thickness of the surrounding material of the curved piston  
6 suspension assembly.

7 The inventor hereby incorporates the above patents by  
8 reference.

9 SUMMARY OF THE INVENTION

10 The present invention is directed to an electron-  
11 dynamic acoustical transducer. The transducer includes a  
12 frame, a diaphragm, a voice coil and a surround. The  
13 diaphragm is secured to the frame by the surround.

14 In a first aspect of the invention the surround is a  
15 single, large, semi-circular corrugation constructed from  
16 compressed neoprene foam rubber.

17 In a second aspect of the invention the surround has a  
18 plurality of radially distributed, relatively less-



1 compressed areas.

2 Other aspects and many of the attendant advantages will  
3 be more readily appreciated as the same becomes better  
4 understood by reference to the following detailed  
5 description and considered in connection with the  
6 accompanying drawing in which like reference symbols  
7 designate like parts throughout the figures.

8 The features of the present invention which are  
9 believed to be novel are set forth with particularity in the  
10 appended claims.

11 DESCRIPTION OF THE DRAWINGS

12 Fig. 1 is a schematic drawing of a loudspeaker.

13 Fig. 2 is a side elevation in cross-section of the  
14 loudspeaker of FIG. 1.

15 Fig. 3 is a side elevation of a loudspeaker that U. S.  
16 Patent No. 4,138,594 teaches.

17 Fig. 4 is a side elevation of a loudspeaker that U. S.  
18 Patent No. 3,912,866 teaches.

1        Fig. 5 is a side elevation of a loudspeaker that U. S.  
2        Patent No. 4,313,032 teaches.

3        Fig. 6 is a cross-sectional view of the loudspeaker of  
4        Fig. 5 taken along the line 6--6 of Fig. 5.

5        Fig. 7 is a cross-sectional view of the loudspeaker of  
6        Fig. 5 taken along the line 7--7 of Fig. 5.

7        Fig. 8 is a schematic drawing of a loudspeaker that  
8        includes a compression chamber, a transducer and a straight  
9        horn.

10       Fig. 9 is a schematic drawing of the loudspeaker of  
11       Fig. 8 that includes a first transducer and a second  
12       transducer mechanically and acoustically coupled to the  
13       compression chamber.

14       Fig. 10 is a schematic drawing of a loudspeaker that  
15       includes a compression chamber, a transducer and a flat  
16       folded horn.

17       Fig 11 is a schematic drawing of the loudspeaker of  
18       FIG. 8 that includes a transducer mechanically and

1 acoustically coupled to the compression chamber.

2 Fig. 12 is a schematic drawing of a loudspeaker that  
3 includes a compression chamber, a transducer and a split  
4 bent horn.

5 Fig. 13 is a schematic drawing of the loudspeaker of  
6 Fig. 8 that includes a first transducer and a second  
7 transducer mechanically and acoustically coupled to the  
8 compression chamber.

9 Fig. 14 is a schematic drawing of a loudspeaker that  
10 includes a compression chamber, a transducer and a corner-  
11 less corner folded horn.

12 Fig. 15 is a schematic drawing of the loudspeaker of  
13 FIG. 8 that includes a transducer mechanically and  
14 acoustically coupled to the compression chamber

15 Fig. 16 is a perspective drawing of a loudspeaker.

16 Fig. 17 is a partial perspective drawing of the  
17 loudspeaker of FIG. 16.

18 Fig. 18 is a perspective drawing of a loudspeaker.

1        Fig. 19 is a partial perspective drawing of the  
2        loudspeaker of Fig. 16.

3        Fig. 20 is an elevation in cross-section of an  
4        electron-dynamic acoustical transducer with a first  
5        surround.

6        Fig. 21 is an enlarged, elevation in cross-section of  
7        the first surround of Fig. 20.

8        Fig. 22 is an enlarged, elevation in cross-section of s  
9        a second surround.

10       Fig. 23 is an enlarged, elevation in cross-section of a  
11       third surround.

12       Fig. 24 is a perspective view of a subwoofer that U. S.  
13       Patent No. 6,130,954 teaches.

14       Fig. 25 is an elevation in cross-section of the  
15       subwoofer of Fig. 25 taken substantially along the line  
16       25-25 in Fig. 24 in order to depict a voice coil driven  
17       woofer and a mass driven woofer as they are mounted within a  
18       cabinet cube.

1        Fig. 26 is an enlarged elevation in cross-section of  
2 the voice coil driven woofer of Fig. 25.

3        Fig. 27 is an elevation in cross-section of the mass  
4 driven woofer and the voice coil driven woofer that include  
5 movable components. The movable components are a surround,  
6 a spider and mass of the mass driven woofer and a voice coil  
7 former, a voice coil, a speaker cone, a spider and a  
8 surround of the voice coil driven woofer.

9        Fig. 28 is a perspective drawing of a subwoofer that  
10 has a transducer and two passive radiators according to the  
11 present invention.

12       Fig. 29 is a side elevation of one of the two passive  
13 radiators of Fig. 28.

14       Fig. 30 is an elevation in cross-section of the  
15 subwoofer of Fig. 28 taken along the lines 30-30 of Fig. 28.

16       Fig. 31 is an elevation in cross-section of the  
17 subwoofer of Fig. 28 taken along the lines 31-31 of Fig. 28.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Fig. 1 in conjunction with Fig. 2 a loudspeaker 10 includes a compression chamber 11, a transducer 12 and a straight horn 13. The transducer 12 is disposed in the compression chamber 11. The output of the loudspeaker 10 is a monopole and therefore is omnidirectional. A first transducer 21 and a second transducer 22 are mechanically and acoustically coupled to the straight horn 12. When the first and second transducers 21 and 22 are added to the transducer 12 their radiation output in the front of the loudspeaker 10 is a dipole and in phase augmentation sharing the monopath of the output of the transducer 12 and their output in the rear of the loudspeaker 10 is out of phase of with the output of the transducer 12. The combined monopole and dipole produces a cardioid-shaped wave. A typical sealed chamber horn radiation is omnidirectional because the mouth area is small compared to the wavelength it is projecting, i.e. 36

1 feet at 30 Hz. An infinite horn would be directional. A  
2 practical horn rarely exceeds three feet in diameter. Hence  
3 the pattern is almost omni-direction in the thirty to ninety  
4 eight (30 to 98) Hz region also the effectiveness fall  
5 rapidly despite the taper near the thirty Hz cut-off usually  
6 beginning an octave higher. Klipsch in his article,  
7 entitled "A Low Frequency Horn of Small Dimensions",  
8 published in The Journal Acoustical Society of America,  
9 Volume 13, Number 2, 1941, pages 137-144, derives the  
10 analytical expression for the volume of a back air chamber.  
11 Theoretically, the back air chamber should be about 10-20%  
12 larger to compensate for the flexure of the suspended  
13 diaphragm and for the immersed volume of the electromagnet  
14 of the electro-acoustic transducer. Since a 20% change in  
15 the volume of a back air chamber has been found to produce  
16 less than approximately 1 decibel of response error and  
17 since error toward a smaller back air chamber results in  
18 less modulation distortion due to subsonic inputs, the back

1 air chamber preferably has a volume of 2,730 cubic inches,  
2 or 44.74 liters, so that the volume is only 2%, rather than  
3 10-20%, larger than the analytical value.

4 Referring to Fig 3 the loudspeaker 30 of U. S. Patent  
5 No. 4,138,594 includes a compression chamber 31, a  
6 transducer 32 and a folded horn 33 in an enclosure 34. The  
7 transducer 32 is disposed in the compression chamber 31.  
8 The output of the loudspeaker 30 is a monopole and therefore  
9 is omnidirectional.

10 Referring to Fig 4 the loudspeaker 40 of U. S. Patent  
11 No. 3,912,866 includes a compression chamber 41, a  
12 transducer 42 and a folded horn 43 in an enclosure 44. The  
13 transducer 42 is disposed in the compression chamber 41.  
14 The output of the loudspeaker 40 is a monopole and therefore  
15 is omnidirectional.

16 Referring to Fig 5 in conjunction with Fig 6 and Fig 7  
17 the loudspeaker 50 of U. S. Patent No. 4,313,032 includes a  
18 compression chamber 51, a transducer 52 and a folded horn 53



1 in an enclosure 54. The transducer 52 is disposed in the  
2 compression chamber 51. The output of the loudspeaker 40 is  
3 a monopole and therefore is omni-directional.

4 Referring to Fig 8 and page 186 of a chapter on  
5 Enclosures in a book, entitled Hi-Fi Loudspeakers and  
6 Enclosure, Revised Second Edition, written by Abraham B.  
7 Cohen, published by Hayden Book Company Cohen describes a  
8 loudspeaker. A loudspeaker 110 includes a compression  
9 chamber 111, a transducer 112 and a straight horn 113. The  
10 transducer 112 is disposed in the compression chamber 111.  
11 The output of the loudspeaker 110 is a monopole and  
12 therefore is omni-directional.

13 Referring to Fig 8 in conjunction with Fig 9 a first  
14 transducer 121 and a second transducer 122 are mechanically  
15 and acoustically coupled to the straight horn 113. When the  
16 first and second transducers 121 and 122 are added to the  
17 transducer 112 their radiation output in the front of the  
18 loudspeaker 110 is a dipole and in phase augmentation

1 sharing the monopath of the output of the transducer 112 and  
 2 their output in the rear of the loudspeaker 110 is out of  
 3 phase of with the output of the transducer 112. The  
 4 combined monopole and dipole produces a cardiode-shaped  
 5 wave.

6 Referring to Fig 10 and page 186 of the book, entitled  
 7 Hi-Fi Loudspeakers and Enclosure, a loudspeaker 210 includes  
 8 a compression chamber 211, a transducer 212 and a flat  
 9 folded horn 213. The transducer 212 is disposed in the  
 10 compression chamber 211. The output of the loudspeaker 210  
 11 is a monopole and therefore is omnidirectional.

12 Referring to Fig 10 in conjunction with Fig 11 a  
 13 transducer 221 is mechanically and acoustically coupled to  
 14 the flat folded horn 212. When the transducer 121 is added  
 15 to the transducer 212 its radiation output in the front  
 16 of the loudspeaker 210 is a dipole and in phase augmentation  
 17 sharing the monopath of the output of the transducer 212 and  
 18 their output in the rear of the loudspeaker 210 is out of

1 phase of with the output of the transducer 212. The  
2 combined monopole and dipole produces a cardioid-shaped  
3 wave.

4 Referring to Fig 12 and page 186 of the book, entitled  
5 Hi-Fi Loudspeakers and Enclosure, a loudspeaker 310 includes  
6 a compression chamber 311, a transducer 312 and a split bent  
7 horn 313. The transducer 312 is disposed in the compression  
8 chamber 311. The output of the loudspeaker 310 is a  
9 monopole and therefore is omni-directional.

10 Referring to Fig 13 in conjunction with Fig 12 a first  
11 transducer 321 and a second transducer 322 are mechanically  
12 and acoustically coupled to the split bent horn 312. When  
13 the first and second transducers 321 and 322 are added to  
14 the transducer 312 their radiation output in the front of  
15 the loudspeaker 310 is a dipole and in phase augmentation  
16 sharing the monopath of the output of the transducer 312 and  
17 their output in the rear of the loudspeaker 310 is out of  
18 phase of with the output of the transducer 312. The combined

monopole and dipole produces a cardioid-shaped wave.

Referring to Fig 14 and page 186 of the book, entitled Hi-Fi Loudspeakers and Enclosure, a loudspeaker 410 includes a compression chamber 411, a transducer 412 and a cornerless corner folded horn 413. The transducer 412 is disposed in the compression chamber 411. The output of the loudspeaker 410 is a monopole and therefore is omnidirectional.

Referring to Fig 14 in conjunction with Fig 15 a transducer 421 is mechanically and acoustically coupled to the cornerless corner folded horn 412. When the transducer 421 is added to the transducer 412 its radiation output in the front of the loudspeaker 410 is a dipole and in phase augmentation sharing the monopole of the output of the transducer 412 and their output in the rear of the loudspeaker 410 is out of phase with the output of the transducer 412. The combined monopole and dipole produces a cardioid-shaped wave.

1 Referring to Fig 16 in conjunction with Fig 17 a first  
2 loudspeaker 510 includes a compression chamber 511, a first  
3 electro-acoustic transducer 512 and a flat folded horn 513  
4 and a rectangular structure 514. The electroacoustic  
5 transducer 512 is disposed inside the compression chamber  
6 511. The first loudspeaker 510 also includes a second  
7 electro-acoustic transducer 521 which is disposed outside  
8 the compression chamber 511 and is mechanically and  
9 acoustically coupled to the flat folded horn 513.

10 Referring to Fig 18 in conjunction with Fig 19 a second  
11 loudspeaker 610 includes a compression chamber 611, a first  
12 electro-acoustic transducer 612 and a flat folded horn 613  
13 and a rectangular structure 614 with a rear extension 615.  
14 The electroacoustic transducer 612 is disposed inside the  
15 compression chamber 611. The second loudspeaker 610 also  
16 includes a second electroacoustic transducer 621 that is  
17 disposed outside the compression chamber 611 and is  
18 mechanically and acoustically coupled to the flat folded

1 horn 613.

2 Referring to Fig. 20 a first loudspeaker 710 includes a  
3 loudspeaker frame 711 having an outer mounting flange 712.  
4 The outer mounting flange 712 includes an outer edge 713 and  
5 an inner edge 714. A first surround 715 has an outer  
6 periphery 716 and an inner periphery 717. The outer  
7 periphery 716 is attached to the mounting flange 712. The  
8 inner periphery 717 of the first surround 715 is attached to  
9 a diaphragm 718 at its outer periphery 719. The first  
10 surround 715 is attached to the mounting flange 712 and the  
11 diaphragm 718 by conventional means in the industry such as  
12 the application of adhesives.

13 Still referring to Fig. 20 the first loudspeaker 710  
14 also includes a top plate 720, a magnet 721, a back plate  
15 722, a pole piece 723 and a voice coil 724 and a spider 725.  
16 A magnetic gap is created between the inner edge of the top  
17 plate 720 and the pole piece 723. A dust cap 726 prevents  
18 foreign particles from entering the gap area. Wiring is

1 also provided. The surround 715 is shown attached at its  
2 first outer periphery to the outer periphery of the mounting  
3 flange 712 of the frame 711, instead of inner periphery. A  
4 second inner periphery of the surround 715 is attached to  
5 the diaphragm 18 at its outer periphery.

6 Referring to Fig. 21 in conjunction with Fig. 20 the  
7 first surround 715 is U-shaped. The first surround 715 is  
8 formed from a single, large, semi-circular corrugation and  
9 is constructed by compressing neoprene foam rubber. The  
10 first surround 715 has a plurality of radially distributed,  
11 relatively less-compressed areas 730. One purpose of the  
12 first surround 715 is to help keep the diaphragm 718  
13 centered and to provide a portion of the restoring force  
14 that keeps the voice coil 724 in the gap defined between the  
15 pole piece 723 and the top plate 720 of the first  
16 loudspeaker 710. The first surround 715 provides a damped  
17 termination for the edge of the diaphragm 718. The  
18 thickness of the first surround 715 can greatly alter the

1 response of the first loudspeaker 710.

2 Referring to Fig. 22 in conjunction with Fig. 20 a  
3 second loudspeaker 810 includes a second surround 815. The  
4 second surround 815 includes a single, large, semi-circular  
5 corrugation constructed from compressed neoprene foam  
6 rubber. The second surround 815 is semi-circular in shape.  
7 The second surround 815 is formed from a single, large,  
8 semi-circular corrugation and is constructed by compressing  
9 neoprene foam rubber. The second surround 115 has a  
10 plurality of radially distributed, relatively less-  
11 compressed areas 830. One purpose of the second surround  
12 815 is to help keep the diaphragm 718 centered and to  
13 provide a portion of the restoring force that keeps the  
14 voice coil 724 in the gap defined between the pole piece 723  
15 and the top plate 720 of the second loudspeaker 810. The  
16 second surround 815 provides a damped termination for the  
17 edge of the diaphragm 718. The thickness of the second  
18 surround 815 can greatly alter the response of the second



1   loudspeaker 810.

2           Referring to Fig. 23 in conjunction with Fig. 20 a  
3   third loudspeaker 910 includes a third surround 915. The  
4   third surround 915 includes a single, large, semi-circular  
5   corrugation constructed from compressed neoprene foam  
6   rubber. The third surround 915 is S-shaped. The third  
7   surround 915 has a plurality of radially distributed,  
8   relatively less-compressed areas 930. One purpose of the  
9   third surround 915 is to help keep the diaphragm 718  
10   centered and to provide a portion of the restoring force  
11   that keeps the voice coil 724 in the gap defined between the  
12   pole piece 723 and the top plate 720 of the third  
13   loudspeaker 910. The third surround 915 provides a damped  
14   termination for the edge of the diaphragm 718. The  
15   thickness of the third surround 915 can greatly alter the  
16   response of the third loudspeaker 910.

17           Referring to Fig. 20 in conjunction with Fig. 21, Fig.  
18   22 and Fig. 23 the thickness (4x) of the radially

1 distributed, relatively less-compressed areas 730, 830 and  
2 930 are four times the thickness (x) of the relatively more-  
3 compressed area of the remaining areas. The densities of  
4 the radially distributed, relatively less-compressed areas  
5 730, 830 and 930 are one-fourth the density of the  
6 relatively more-compressed area of the remaining areas.  
7 Other ratios between the thicknesses of the radially  
8 distributed, relatively less-compressed areas 730, 830 and  
9 930 and the thickness (x) of the relatively more-compressed  
10 area of the remaining areas may be used. The densities of  
11 the radially distributed, relatively less-compressed areas  
12 730, 830 and 930 are the reciprocal (1/ratio) the density of  
13 the relatively more-compressed area of the remaining areas.  
14 These radially distributed, relatively less-compressed  
15 areas 730, 830 and 930 provide increased flexibility in a  
16 direction that is orthogonal to the diaphragm 718 without  
17 losing any rigidity in any direction within the plane of the  
18 diaphragm 718 because no material has been removed from the

1 compressed neoprene foam rubber as in a slotted surround.  
 2 U. S. Patent No. 4,433,214 teaches the slotted surround.  
 3 Referring to Fig. 24 in conjunction with Fig. 25 a  
 4 subwoofer 1050 includes a cabinet 1051 that encloses two  
 5 drivers 1052 and 1054. The drivers 1052 and 1054 are each  
 6 oriented in a PUSH/PULL configuration on opposite sides of  
 7 the cabinet 1051. The driver 1052 includes a mass driven  
 8 driver and is mounted in one wall of the cabinet 1051 (here  
 9 the left sidewall 1055 of the cabinet 1051) and fires in  
 10 PUSH/PULL directions. The second driver 1054 is mounted in  
 11 the opposite or right sidewall 1056 of the cabinet 1051 and  
 12 simultaneously fires in corresponding PUSH/PULL directions.  
 13 Both drivers 1052 and 1054 move simultaneously in a PUSH (or  
 14 outward) direction and imultaneously in a PULL (or inward)  
 15 direction. The cabinet 1051 is a substantially cubic  
 16 structure with a front wall, a rear wall 1058 that includes  
 17 a control panel, left and right sidewalls 1055 and 1056  
 18 within which the woofer drivers 1052, 1054 are mounted, a

1 top wall 1059 and a bottom wall. All walls are constructed  
 2 of a rigid, non-resonant, inert material such as MDF type  
 3 particle-board, wood, or the like. Each panel or wall can  
 4 have a suitable finish applied thereto such that the  
 5 subwoofer can match the furnishings of the room where it  
 6 will be installed. The drivers 1052, 1054 may, if desired,  
 7 be covered by an acoustically transparent material. The  
 8 rear wall 1058 containing the control panel a Power ON/OFF  
 9 indicator light 1060, three control knobs for permitting  
 10 manual adjustment of Bass Level 1061, Crossover Frequency  
 11 1062 and Phase 1064, a manually operable toggle switch 1065  
 12 for selecting between Video Contour and Flat operation, one  
 13 pair of right and left female input jacks 1066 and one pair  
 14 of right and left female input posts 1068 for permitting  
 15 inputting of audio signals, one pair of right and left  
 16 female output jacks 1069, a fuse 1070 and an A.C. outlet  
 17 plug 1071 and power cord 1072. The audio signal input jacks  
 18 1066, 1068, 1069 can be connected to any suitable cables

1 which bring the audio signal to the subwoofer 1050. The  
2 front, rear, side, top and bottom panels of the cabinet 1051  
3 are fixed to each other to form the cabinet using known  
4 techniques. The cabinet 1051 is preferably sealed so that  
5 air can neither enter nor exit. Feet 1074 may be placed on  
6 the bottom panel 1075. The feet 1074 are of sufficient  
7 strength to support the subwoofer 1050, and formed of non-  
8 skid material capable of providing some sound or vibration  
9 insulation. The subwoofer 1050 employs two drivers that are  
10 the mass driven driver or woofer 1052 mounted in the left  
11 sidewall 1055 of the cabinet 1051 and the voice coil driven  
12 driver 1052 mounted in the right sidewall 1056 of the  
13 cabinet 1051. The mass driven woofer 1052 includes a  
14 stationary frame or cage 1076 mounted in the left sidewall  
15 1055 of the cabinet 1051 for resiliently supporting the  
16 moving driver components in a stable manner. The movable  
17 driver components are constrained for PUSH/PULL movement  
18 axially out of and axially into the cabinet. The movable

1 driver components in the mass driven driver 1052 includes a  
2 resilient, but semi-rigid, high pressure resistant surround  
3 1078 formed of an expanded synthetic cellular foam as an  
4 expanded cellular polyethylene ("PE") surround foam and  
5 including a generally circular element having an outer  
6 peripheral circumferential flange 1079, an annular half roll  
7 or "edgeroll" 1080 integral with the flange 1079 and  
8 terminating in an inner annular inturned or downturned  
9 integral flange 1081 which is, in turn, integral with a flat  
10 central disk portion 1082. A rigid backing plate 1084  
11 formed of paperboard, plastic or the like is adhesively  
12 bonded to the central disk portion 1082 of the surround  
13 1078. A round rod-shaped metal mass 1085 weighing  
14 approximately one and seven-tenths pounds (1.7 lbs.) is  
15 secured to the backing plate 1084 within a cardboard or  
16 paperboard cylindrical tube 1086 by means of a suitable  
17 epoxy glue 1088. Finally, the movable components of the  
18 mass driven woofer 1052--which collectively approximate two

1 pounds (2.0 lbs.) in the aggregate--include an annular  
 2 flexible spider 1089 having a corrugated cross-sectional  
 3 configuration wherein the corrugations get progressively  
 4 deeper towards the outer periphery of the spider 1089. The  
 5 outer periphery of the spider 1089 is fixedly secured to the  
 6 frame or cage 1076 of the mass driven woofer 1052, while its  
 7 inner periphery is fixedly secured to the cylindrical  
 8 cardboard or paperboard tube 1086 surrounding the mass 1085.

9 Referring to Fig. 26 in conjunction with Fig. 25 the  
 10 voice coil driven woofer 1054 includes a stationary basket-  
 11 like frame or cage 1090 which is fixedly mounted in the  
 12 right sidewall 1056 of the cabinet 1051. The base of the  
 13 frame 1090 includes an annular washer-shaped flange 1091  
 14 which is secured to an annular metal top spacer 1092  
 15 adjacent which is positioned an annular magnet 1094 having  
 16 an external diameter of approximately 107 and 11/16 inches,  
 17 an internal diameter of approximately 31/2 inches, a depth  
 18 of approximately 1.75 inches or slightly greater, and a

1 weight of approximately 225 ounces (approximately 14 pounds,  
2 1 ounce). The magnet 1094 comprises a single-piece magnet  
3 having a depth or length of approximately 1.75 inches; but,  
4 as those skilled in the art will appreciate, the magnet 1094  
5 can be formed of two or more magnet segments which, when  
6 assembled in end-to-end relation, have the approximate  
7 dimensional and weight characteristics. The bottom face of  
8 the annular magnet 1094 is spaced from an annular metal  
9 bottom plate 1095 by an annular spacer 1096. The final  
10 stationary member of the voice coil driven woofer 1054  
11 includes an annular pole piece 1098 having an external  
12 diameter of approximately 3 inches. The arrangement is such  
13 that the outer diameter of the annular pole piece 1098  
14 defines an annular gap 1099--termed the "magnetic gap"--  
15 between the pole piece 1098 and the upper annular spacer  
16 1092 with the annular magnetic gap being approximately 0.1"  
17 to about 0.25" in radial width. The movable components of  
18 the voice coil driven woofer 1054 includes an expanded



1 synthetic cellular foam surround 1078 that is an expanded  
 2 cellular polyethylene ("PE") foam surround, that is  
 3 substantially identical to the surround 1078 employed with  
 4 the mass driven woofer 1052 previously described except that  
 5 the central disk-shaped portion 1082 of the surround 1078  
 6 associated with the mass driven woofer 1052 has been removed  
 7 in the surround 1078' employed with the voice coil driven  
 8 woofer 1054, a speaker cone 1100 having a funnel shape with  
 9 its outer large diameter end 1101 being adhesively bonded or  
 10 otherwise fixedly secured to the inner inturned flange 1081  
 11 on the surround 1078', a cylindrical voice coil former 1102  
 12 having an inner diameter slightly greater than the outer  
 13 diameter of the annular pole piece 1098, a voice coil 1104  
 14 wound about the voice coil former and having an outer  
 15 diameter slightly less than the inner diameter of the upper  
 16 annular spacer 1092, a rigid dust cover or surround support  
 17 1105 having a shape comprising a segment of a sphere which  
 18 is positioned within, and secured to, the funnel-shaped

1 speaker cone 1100 with the domed portion of the dust  
 2 cover/support facing outwardly; vi) a decorative cover 1106  
 3 formed of expanded cellular polyethylene ("PE") surround  
 4 foam, or similar material, positioned within, and secured  
 5 to, the outermost large diameter end 1101 of the speaker  
 6 cone 1100 with the decorative cover 1106 abutting the dust  
 7 cover/support at their respective midpoints, and annular  
 8 spider 1108 having a corrugated cross section wherein the  
 9 depth of the corrugations progressively increase from the  
 10 inner periphery towards the outer periphery with the spider  
 11 1108 being secured at its innermost periphery to the outer  
 12 surface of the voice coil former 1102 and at its outer  
 13 periphery to the frame or cage 1090 of the apparatus. The  
 14 arrangement is such that when positive or negative voltage  
 15 levels are output from the tracking down-converter-drive  
 16 amplifier which is capable of delivering 2,700 watts rms to  
 17 a nominal 4 ohm resistive load and swinging 104 volts rms--  
 18 and applied to the voice coil 1104, current flows through

1 the voice coil 1104 creating magnetic fields around the  
 2 voice coil. These voice coil magnetic fields interact with  
 3 the magnetic field of the magnet 1094, causing the voice  
 4 coil former 1102, voice coil 1104, speaker cone 1100, dust  
 5 cover 1105, surround 1078', decorative cover 1106 and spider  
 6 1108 to move in an axial direction--e.g., in an outward  
 7 axial PUSH direction when positive voltage levels are output  
 8 from the tracking down converter-drive amplifier; and, in an  
 9 inward axial PULL direction when negative voltage levels are  
 10 output from the tracking downconverter drive amplifier. The  
 11 movable voice coil former 1102 and voice coil 1104 move  
 12 axially within the magnetic gap 1099 between the annular  
 13 pole piece 1098 and the annular upper spacer 1092 with a  
 14 PUSH/PULL movement dependent upon the polarity of the  
 15 voltage applied to, and the current flow in, the voice coil  
 16 1104. Since the voice coil former 1102 and voice coil 1104  
 17 reciprocate axially within the magnetic gap 1099--i.e., move  
 18 to the left and to the right. The speaker cone 1100



1 The accelerometer 109 serves to sense the movement of the  
 2 movable components of the voice coil driven woofer 1054 and  
 3 any movement distortion, with signals representative of such  
 4 movement and any such distortions being conveyed to the  
 5 processing circuitry discussed hereinafter.

6 Referring to Fig. 27 in conjunction with Fig. 26 the  
 7 surround 1078' is intended for use in supporting a speaker  
 8 cone 1100 having an effective 108" diameter that would  
 9 normally be mounted in a basket-like frame or cage 1090  
 10 having a diameter of approximately 10". When the surround  
 11 is intended for use with a speaker cone 1100 having an  
 12 effective 10" diameter and mounted in a basket-like frame or  
 13 cage 1090 having a diameter of approximately 12", the  
 14 surround 1078' will have a diameter of approximately 11.9",  
 15 a uniform thickness on the order of at least 0.14", or more,  
 16 an outer peripheral flange 1079 approximately 0.3875" wide,  
 17 and an edgeroll 1080 having an I.D. of approximately 1.5".  
 18 Conventional surrounds are, and have been, typically

1 fabricated from, for example, an expanded cellular  
 2 polyethylene ("PE") surround foam sheet which is  
 3 approximately 107/16" in thickness and which is compressed  
 4 to form a very resilient, compliant suspension member having  
 5 a thickness of approximately 0.02". Such conventional prior  
 6 art surrounds are very thin and flexible, often having  
 7 little more rigidity than rubber gloves; and, consequently,  
 8 have very little ability to stand off internal pressures  
 9 within the woofer box 1051. However, since conventional  
 10 woofers generally generate internal pressures of only on the  
 11 order of about 0.1 lbs/in.sup.2 to about 0.2 lbs/in.sup.2,  
 12 and normally have peak-to-peak strokes of only 0.4" to 0.6",  
 13 the conventional thin, highly flexible, compliant prior art  
 14 surrounds have generally been acceptable. Typically such  
 15 conventional surrounds will have an outer half roll or  
 16 "edgeroll" of not more than, and usually less than, one inch  
 17 in diameter. As will be described hereinbelow, the mass  
 18 driven woofer 1052 and voice coil driven woofer 1054 of the

1 present invention are driven through peak-to-peak excursions  
2 up to about 2.5" as contrasted with conventional woofers  
3 which typically have peak-to-peak excursions ranging from  
4 only about 0.4" to about 0.6"--i.e., the movable components  
5 of the drivers 1052, 1054 are driven to excursions ranging  
6 from five to six times the excursions typically generated in  
7 conventional subwoofers.

8 Referring to Fig. 28 a subwoofer 1210 includes a  
9 cabinet 1211, a transducer 1212 and two passive radiators  
10 1220. The transducer 1212 and the two passive radiators are  
11 disposed in the cabinet 1211. The cabinet 1211 is  
12 substantially air-tight.

13 Referring to Fig. 29 each passive radiator 1220  
14 includes a surround 1221 and a flat, circular piece 1222 of  
15 wood.

16 Referring to Fig. 30 in conjunction with Fig. 31 the  
17 subwoofer 1210 is disposed orthogonally to the two passive  
18 radiators 1212. The two passive radiators 1220 are

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1 resiliently coupled by an elastic member 1223 in order to  
2 overcome both the air pressure and the vacuum created by the  
3 push-pull action of the two passive radiators 1220.

4 While this invention has been particularly shown and  
5 described with references to preferred embodiments thereof,  
6 it will be understood by those skilled in the art that  
7 various changes in form and details may be made therein  
8 without departing from the spirit and scope of the invention  
9 as defined by the appended claims

10 It should be noted that the sketches are not drawn to  
11 scale and that distance of and between the figures are not  
12 to be considered significant.

13 Accordingly it is intended that the foregoing  
14 disclosure and showing made in the drawing shall be  
15 considered only as an illustration of the principle of the  
16 present invention.